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SECTIONS USING MEASURED NEUTRON SPECTRA
FROM THICK SHELLS OF Ta, W, Mo, AND Be**

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AN INTEGRAL TEST OF INELASTIC SCATTERING CROSS SECTIONS USING MEASURED
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ABSTRACT

Measured and calculated sphere leakage spectra in the energy range 0.5 to 11 MeV are used as a test of the accuracy of existing ENDF/B cross sections. Inelastic reactions are the primary cause of the large shift in the source spectrum as it traverses the spherical shell. A 50 Ci AmBe source was used as a source of fast neutrons at the center of 22 cm diameter spheres. The leakage spectra were measured at a distance of several hundred cm using an NE213 liquid scintillator neutron spectrometer. Room scattered neutron backgrounds were accounted for using a shadow cone. The spectra were calculated with 51 groups using ENDF/B and other cross sections and an S_n discrete ordinate transport code. The sensitivity of the leakage spectra to small changes in the cross sections has been calculated. A comparison between the calculated and measured spectra for Mo shows general agreement but significant discrepancies are observed for W, Ta, and Be.

INTRODUCTION

A radioactive Be (α, n) neutron source is used in conjunction with a fast neutron spectrometer to test cross sections in the energy range 500 keV to 11 MeV. The elements tested are of interest for compact reactors and minimum weight shields for space power applications and include Ta, W, Mo, Be. The (α, n) source was placed inside spheres of the test material and the leakage spectrum measured at a distance of about 10 sphere diameters. With this simple geometry it was possible to make a transport calculation with a large number of energy groups and to reduce the uncertainty in the calculation to essentially the input cross sections.

The leakage spectra were measured with a large liquid scintillator which has the advantage of high sensitivity and a great deal is known about the response of this scintillator to neutrons. The resolution of the spectrometer is poorer than time-of-flight measurements but it is fairly comparable at the highest energies measured to the width of the neutron group structure of the largest transport calculation we can presently muster.

EXPERIMENT

The sphere leakage spectra were measured at a sphere-to-spectrometer distance of 2 meters with both the sphere and spectrometer located 160 cm above the floor of a large room. Background due to neutrons scattered into the spectrometer from the walls and supporting structure was accounted for using a shadow cone. This correction to the measurement was negligible at the highest neutron energies measured but increased to 30% at the lowest energy measured. The measurements were made with a large spherical Am-Be neutron source containing 54 Ci of ^{241}Am (16.7 g) and 66.8 grams of Be in a net volume of 84.3 cm³. The output of the source was $(1.30 \pm 0.08) \times 10^8$ neutrons per second. The outside diameter of the source is 6.096 cm and includes two stainless steel containment shells, one 0.140-cm thick and the other 0.152-cm thick. The spherical cavity for the source material is 5.462 cm inside diameter.

The neutron spectra were measured using a 5 cm \times 5 cm NE213 liquid scintillator proton recoil spectrometer. Pulse shape analysis and two parameter data acquisition were used to discriminate against γ ray pulses. A description of the spectrometer and calibration procedures are contained in reference 1. For a scintillator as large as that used here, care must be exercised in determining the neutron spectra from the measured proton recoil spectra due to multiple scattering and carbon interaction in the scintillator.

In the present work the measured proton recoil spectra were reduced using the measurements of Verbinski, et al² and the unfolding code, Ferdor³. Since the present measurements are in an essentially parallel beam geometry, the reference 2 response functions are directly applicable. To assure that small differences in scintillator size or spectrometer resolution did not cause a significantly different response matrix fit, monoenergetic spectra were measured at 2.8 and 14.7 MeV and detailed comparison satisfactorily made with the reference 2 response functions.

TRANSPORT CALCULATIONS

Multigroup calculations using the S_n formulation of the neutron transport equation were used to obtain the leakage spectrum for all of the experiments considered. The calculations were performed in spherical geometry with shells of the test material enclosing the Am-Be neutron source. The Am-Be neutron source and its stainless steel containers were explicitly included in the calculations both as to dimensions and composition. The calculations were of the fixed source type using an input spectrum uniformly distributed throughout the source region.

Fifty-one energy groups were used to describe the neutron leakage spectrum for the various experiments considered. The first 49 energy groups had a lethargy interval of 0.1 and covered the energy range of 14.92 MeV to 0.11 MeV. The last two groups were provided to complete the problem description. Since the input spectrum is zero above 11 MeV, the first three groups had no contribution to the computed neutron leakage spectra.

Microscopic cross section data for the test materials were obtained from ENDF/B and other evaluations for the group split used. The elastic scattering cross sections for all of the materials included both the P_0 and P_1 down-scattering transfer cross sections. For Mo, Ta, and W the inelastic scattering cross sections, as well as any $(n,2n)$ cross sections, were assumed to have only the P_0 component of the down-scattering transfer cross sections. For Be the $(n,2n)$ cross sections included only the P_0 down-scattering transfer cross sections.

Calculations for the Mo experiment indicated that a $P(1)$ treatment of elastic scattering was adequate for computing the neutron leakage spectrum. Calculations in which the elastic scattering is treated through the $P(1)$ order and through the $P(3)$ order differ by less than 1.5 percent for groups 15 through 49 (3.3 to 0.11 MeV). The difference at group 5 (10 MeV) is about 4 percent.

Along with the elastic scattering order, the S_n quadrature order is important. The calculations reported herein used an S_{16} Gauss-Legendre quadrature set. This set was found to give an adequate description of the leakage spectrum from the spherical shells of the test materials in that a higher order S_{32} calculation differs by less than 0.5% for all groups.

The calculations reported herein are based on the total number of neutrons emitted by the Am-Be source. The neutrons transmitted through the shells of the test material per group are converted to flux per MeV at 2 meters - the source-to-detector position. Then, in order to compare the calculations with the measured spectra, the resolution function of the spectrometer is folded with these calculated multigroup fluxes using a modification of the smoothing subroutine in 05S⁴. Thus, the comparison of the calculated fluxes with the measured fluxes is on an absolute basis with no normalization required.

RESULTS AND DISCUSSION

Bare Source

Rather than use the measured source spectrum as the input spectrum in the transport calculations a modified small source spectrum has been used and the calculation compared with the source measurement. This was done because the large source used contains sufficient Be and Fe to modify the input (α,n) spectrum. In addition the measured source spectrum is smeared by the resolution of the spectrometer, and finally the group structure used was not sufficiently fine to follow the details of the spectrum above about 8 MeV resulting in some disagreement for all spectra not attributable to cross sections.

The measured and calculated source spectrum is shown in figure 1. The comparison is on an absolute basis and therefore involves the uncertainty in the source strength. It is generally good but the calculation has a few percent less total flux above 7 MeV and smoothes out the measured shape changes in this energy region. The (α,n) spectra is not expected to have abrupt

changes in shape in this region but it does have more structure than can be represented by the group structure used. At energies less than 7 MeV the agreement between the calculation and measurement is quite satisfactory.

Mo Sphere

The measured and calculated leakage spectrum from a Mo sphere containing the source is shown in figure 2. The agreement between experiment and calculation is satisfactory and similar to that for the bare source. The sphere size and composition are given in Table 1.

The ENDF/B data for Mo were compiled by Pennington and Gajniak (ref. 5). The inelastic cross sections from 0.2 to 1.5 MeV are based on the values of Smith and Hayes (ref. 6). These data are joined to the values of Schmidt (ref. 7) at 2 MeV. The inelastic data then follows Schmidt values up to 10 MeV above which they are assumed to be constant. This Mo data was issued as ENDF/B material no. 1025. The Mo data was further revised by Pennington in October, 1969. The inelastic cross sections were not changed but the high energy (n, γ) cross sections were reduced approximately 25 percent. This revised Mo data is available as ENDF/B material no. 1111 and was used herein for the leakage spectrum calculation.

W Sphere

The measured and calculated leakage spectrum from the tungsten sphere are shown in figure 3. In the energy range from 3 to 6 MeV the calculation is about 10% below the measurement. In the energy range from 0.8 to 2 MeV the agreement is poor with the calculation about 35% below the measurement.

The tungsten cross section data used for this study was obtained from the GAM-II (ref. 8) data files. This data is based on the evaluation of Joanou and Stevens (ref. 9). A new evaluation by the National Neutron Cross Section Center is currently in progress for the W isotopes. However, these data were not available for inclusion in the work of this paper.

Ta Sphere

The measured and two calculated spectra for the tantalum sphere are shown in figure 4. In the energy range above 6 MeV the calculation is about 10% above the measurement which means for this sphere size that the inelastic cross section is low by about 10%. At energies below 3 MeV the agreement with the ENDF/B cross sections is poor as in the case of tungsten. By changing the mass dependent parameter "a" in the evaporation model from 25 MeV^{-1} as used in ENDF/B to the theoretical value of 17.4 MeV^{-1} , better agreement is obtained between the calculation and the measurement.

The ENDF/B data for Ta-181 was evaluated by Henderson, DeCorrevont, and Zwick (ref. 10). This evaluation is based primarily on the work of Prince

(ref. 11) which was undertaken in support of the 710 Reactor Program at GE-NMPO. This Ta data, as evaluated in reference 10, was issued with corrections and additions, as ENDF/B material no. 1035. A new evaluation by the National Neutron Cross Section Center is currently in progress for the Ta isotopes. However, these data were not available for inclusion in the work of this paper.

Be Sphere

The sphere leakage spectra for beryllium is shown in figure 5. Two calculated spectra are shown with the measured spectra in fair agreement with the lower calculated curve but in poor agreement with the calculation using ENDF/B cross sections.

The two cross section evaluations differ only in the treatment of the (n,2n) reaction. The cross section set listed as ENDF/B no. 1007 is based on the evaluation of Joanou and Stevens (ref. 12). This work provided one of the evaluations for the down-scattering transfer cross sections for the Be (n,2n) reaction. The other evaluation of the Be (n,2n) down-scattering transfer cross sections is based on the work of Perkins (ref. 13) which provides improved agreement.

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TABLE 1. - SPHERE COMPOSITION

Mat.	Form	(gms/cc)	OD (cm)	Container (cm)	Shell thickness (cm)	Shell thickness in total mean free paths at 4 MeV
Be	Metal	1.84	20.32	-----	7.00	1.7
Mo	Powder	3.73	22.96	SS (0.05)	8.38	0.74
Ta	Metal	16.60	24.13	-----	9.02	3.4
W	Fine balls	11.87	22.96	SS (0.05)	8.38	2.0

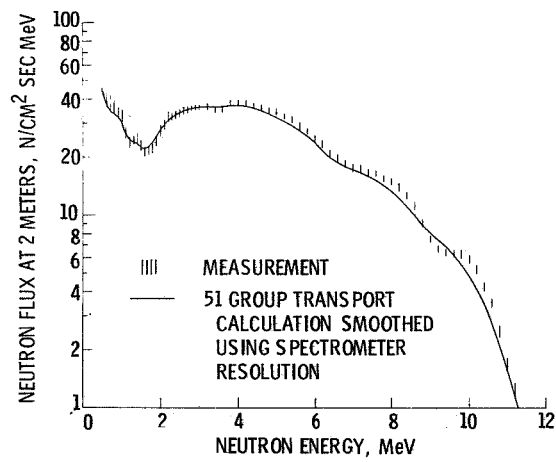


Figure 1. - 54 Curie AmBe source spectrum.

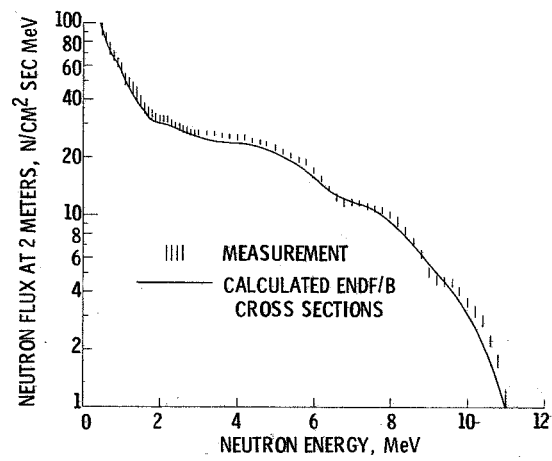


Figure 2. - Leakage spectrum for source enclosed by a molybdenum shell.

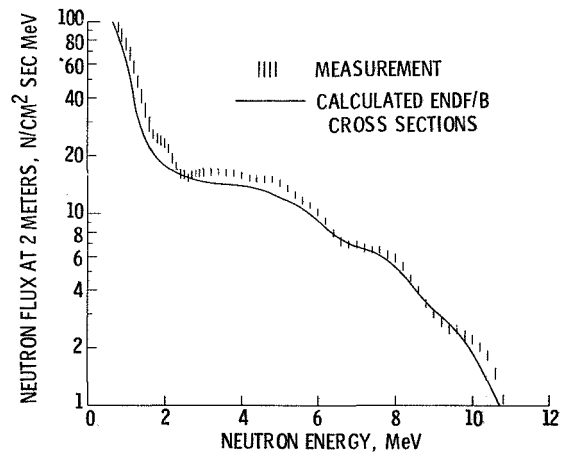


Figure 3. - Leakage spectrum for source enclosed by a tungsten shell.

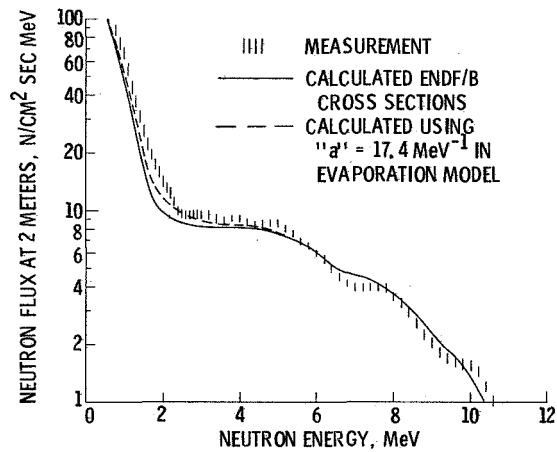


Figure 4. - Leakage spectrum for source enclosed by a tantalum shell.

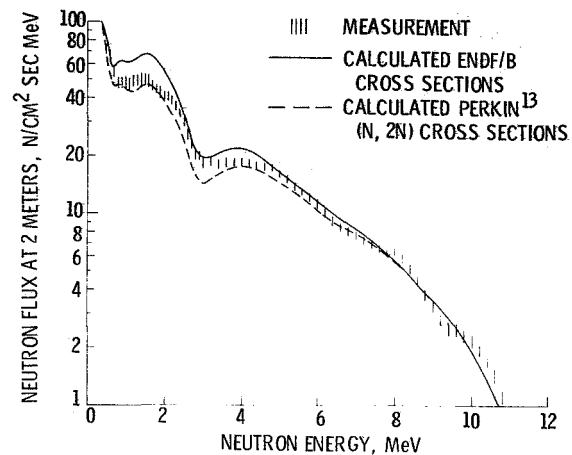


Figure 5. - Leakage spectrum for source enclosed by a beryllium shell.